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Workshop on Crab Assessment Methods

20-23 November, 2001
Montreal, QC

Jake Rice / Chairperson

Canadian Stock Assessment Secretariat
Department of Fisheries and Oceans
200 Kent Street, Ottawa K1A 0E6

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ABSTRACT

The special Zonal Workshop on assessment methods and management approaches for snow crab met from November 21-23 in Montreal, PQ. The workshop was first informed of the results of preceeding workshops on research needs for snow crab. Participants then reviewed the approaches to assessment of crab stock status used in each region, highlighting both the major biological and fisheries considerations that contributed to the approaches used for each stock. Fishery data sources, surveys, and analytical formulations were all addressed in the reviews. Following the review of assessment methods, the management strategies for snow crab used by Fisheries Management in each Region was also presented and discussed.

Workshop participants addressed the requirements for conservation of crab stocks and sustainability of harvesting strategies. A number of factors were found to contribute to maximizing yield from crab stocks. The biological basis for conservation of crab stocks, however, was concluded to be straightforward, as long as the fishery remained male-only, with a minimum size limit that precludes the lowest of females and a portion of mature males. On that basis the workshop moved to evaluating the assessment approaches used in each Region with regard to providing the information necessary for managers to ensure conservation of the stocks and, to the fullest extent practical, achieve maximum yield. Differences in assessments methodologies among Regions were tabulated, and where possible, were linked directly to differences in the needs of fishery managers. A number of recommendations were formulated to improve assessment practices, to link management more closely to biological foundations, and to reduce differences in assessment and management practices among regions, where the differences did not have any identifiable biological or management basis.

RÉSUMÉ

Un atelier zonal spécial sur les méthodes d'évaluation et les approches de gestion du crabe des neiges a eu lieu à Montréal, Québec, du 21 au 23 novembre 2000. Il a débuté par la présentation des résultats des ateliers précédents sur les besoins en recherche sur le crabe des neiges. Les participants ont ensuite passé en revue les approches utilisées par chacunes des régions pour l'évaluation de l'état des stocks, en mettant l'accent sur les principales considérations biologiques et halieutiques qui ont mené à l'utilisation de ces approches. Pour ce faire, les sources de données sur les pêches, les relevés et les formules d'analyse ont été pris en compte. Les stratégies de gestion du crabe des neiges appliquées dans chaque région par Gestion des pêches ont ensuite été présentées et débattues.

À l'examen des impératifs de conservation des stocks de crabe et de la viabilité des stratégies de pêche, les participants ont identifié un certain nombre de facteurs qui contribuent à la maximisation du rendement des stocks pour ensuite conclure que le fondement biologique de la conservation de ceux-ci est simple tant que la pêche ne cible que les mâles et que la limite de taille minimale exclut la possibilité de capture des petites femelles et d'un pourcentage des mâles adultes. En se fondant sur cette conclusion, les méthodes d'évaluation utilisées dans chaque région ont été évaluées en vue de fournir aux gestionnaires les renseignements nécessaires pour assurer la conservation des stocks et, dans la mesure du possible, réaliser un rendement maximum. Les participants ont ensuite mis en tableau les différences entre les méthodes et, lorsque possible, les ont liées directement aux différents besoins des gestionnaires des pêches. Une série de recommandations ont été formulées affin d'améliorer les méthodes d'évaluations, d'établir un lien plus direct entre la gestion et la biologie des stocks et affin de combler les écarts entre les régions en ce qui a trait aux méthodes d'évaluation et de gestion, pour autant que ces écarts nepuissent être justifiés au plan biologique ou gestionnel.

1. OPENING REMARKS

Dr. Jake Rice (Co-ordinator, CSAS) welcomed all participants, on behalf of the Science Branch sponsors and Headquarters. He stressed that the Terms of Reference were very important to the Department, and the conclusions of the meeting would receive substantial attention in the next cycle of assessments and development of advice on management. He also thanked the participants for fitting another meeting into their schedules, and for preparing the many presentations that we would be hearing. He also encouraged presenters to remain within their time allotments to allow ample time for discussion.

2. ADOPTION OF THE AGENDA

It was agreed to move the discussion of the Precautionary Approach to precede the discussion of individual management measures. The process by which the meeting Proceedings would be reviewed and approved was also discussed. Authors are to provide Abstracts of all talks. The brief summaries of major points of discussion on individual talks, and the more complete summaries of general discussions will be circulated for comment on accuracy and completeness when prepared. Revisions will be made in response to comments, and complete revised draft will also be circulated for review before it is considered final.

3. REVIEW OF THE TERMS OF REFERENCE

This discussion was lead by J. Moores, who explained that the major purposes of the workshop were to determine where we are, what we know, what we need to do and how to get there with regard to how status of crab stocks is determined, and what is advised be done, given the status of the stocks.

4. SCIENCE WORKSHOP REPORT (E. Dawe/B. Sainte-Marie)

Workshop on Effects of Temperature on Snow Crab Distribution and Population Dynamics (B. Sainte-Marie)

Summary

A workshop was held during October 2000 in Halifax to review progress in knowledge of the potential impacts of climate change on snow crab distribution and population dynamics, arising from DFO (SRF) and DNR (CCAF) sponsored research. Ten presentations, organised under 4 themes, were given during the workshop. Titles and highlights of presentations are given below; a proceeding with extended abstracts will be published in 2001. Overall, it was concluded that only slight changes in temperature may have profound effects on spatial distribution and population dynamics of snow crab, notably by modifying the areal extent of suitable habitat, density-dependent relationships, growth and reproductive rates, and size at maturity (terminal molt). Moreover, there was large-scale commonality in the temperature threshold for snow crab distribution and evidence that early benthic juveniles are more thermally restricted than larger crabs. This suggests that the settlers may

represent a critical stage in the establishment and propagation of viable populations. Orientations for further research were discussed.

Themes, Titles and Highlights of Presentations

a) Spatial Distribution in Relation to Depth and Temperature

Distribution of Newfoundland and Labrador snow crab in relation to bottom temperature from fall 1995-99 multispecies surveys. E.B. Colbourne, E.G. Dawe & H.J. Drew.

- 2J3KLNO; warming since 1995; no subzero waters in 1999; ≈4°C limit for crab, juveniles seem to prefer colder water; recent abundance of snow crab coincided with long period of below-normal temperature.

Snow crab distribution on the Scotian Shelf from annual groundfish trawl surveys. J. Tremblay & R. Branton.

- Improved assessment of crabs in groundfish survey; Scotian shelf is warming; from 1980-94 snow crab occurred primarily in water <4°C, but now a larger proportion are found in warmer water and possibly represent a relict and doomed population.

Distribution of Gulf of St. Lawrence snow crab in relation to depth and bottom temperature from summer and winter 1984-99 multispecies surveys. B. Sainte-Marie, A. Rondeau & D. Gilbert.

- Crab occur in water up to 7°C, but most frequently in water <4°C; bigger-deeper and bigger-warmer trends observed.

b) Reproductive Cycle and Embryonic Development

Temperature-dependent development of snow crab embryos. *B. Sainte-Marie, A. Rondeau & D. Gilbert.*

- Experimental test of temperature-dependent 1- and 2-yr reproductive cycle; egg incubation lasts 2 yrs at –1.5 and 0 °C and 1 yr at 1.5 and 3 °C; In nature, females have a 2-yr reproductive cycle at <0.75°C and a 1-yr cycle at 2-3.5°C (intermediate temperatures were not found).

Modeling temperature effects on snow crab egg production. D. Gilbert & B. Sainte-Marie.

- Conceptual model of population egg production integrating temperature-dependent female size and reproductive cycle, distributional patterns, size-fecundity relationships, and interannual variability in habitat temperature.

Research into the energy budget of juvenile snow crabs at different temperatures. K. Gravel, D. Chabot, B. Sainte-Marie & C. Audet.

- Preliminary analysis of energy budget of instars II-V at –1.5, 0, 1.5 and 3 °C; higher mortality at 3 °C; O_2 consumption scales to increasing temperature, but nitrogen excretion is greatest at 0 and 1.5 °C suggesting that energy requirements of early juveniles are not met at 3 °C.

c) Relationships between Temperature and Growth

Looking for temperature effects on size at adulthood. B. Sainte-Marie & D. Gilbert.

— Discussion of warmer-larger trend for adult female size; how to look for similar relationships in males given the confounding effects of fishing mortality on large males.

Spatial and annual trends in molt frequency and size-at-adulthood at Newfoundland and Labrador. E.G. Dawe.

— 2J3KLNO; examination of patterns of adolescent to adult males and proportion skip-molters; molting more frequent and consistent in northern (colder) than in southern (warmer) divisions; temperature effect or density-dependence?

d) Definition of Snow Crab Habitat Indices

A Snow Crab Thermal Habitat Index for the Scotian Shelf, the Gulf of St. Lawrence and northern Newfoundland. K.F. Drinkwater.

— Time series of area covered by water –1.5 to 3 °C = crab habitat index; on Scotian Shelf index low in 1970s, variable in 1980s and high in early to mid 1990s but now below long-term normal; on Magdalen shallows index high until 1998 but declined sharply in 1999; highest variability of index seen on Newfoundland Shelf, increasing to 1995 then declining sharply up to 1999. Newfoundland and Scotian Shelf may be marginal habitats due to large interannual variations in habitat index.

Upcoming temperature preferenda studies. B. Sainte-Marie.

— Laboratory studies of megalopae habitat selection, emphasising temperature and substrate preferences.

Workshop on Atlantic Snow Crab Research Requirements (E. Dawe)

Summary

A major constraint to snow crab resource assessment in general is the lack of any capability for reliable long-term recruitment prediction. The relative effects of environmental versus density-dependent effects on recruitment dynamics in the long term are especially unclear, and availability of data pertaining to this problem differs greatly among regions. Strategic Research Funding was provided to support a zonal workshop on Atlantic snow crab research requirements toward improving assessment capability. The workshop was held during October 2000, immediately following a workshop on 'Effects of Temperature on Snow Crab Distribution and Population Dynamics'. It is intended to publish the proceedings and extended abstracts. The objectives of this workshop were;

i) to review the data available and currently being collected so as to determine what additional types of data will be required to expand the knowledge base pertaining to snow crab recruitment mechanisms and population dynamics.

ii) to identify region-specific deficiencies in data availability as well as the research that would be required to address these deficiencies.

iii) to outline a zonally-coordinated comprehensive research program to investigate the relative effects of environmental versus density-dependent effects on distribution and recruitment. This outline would represent the basis of a proposal for future zonal strategic research funding.

Initially, regional presentations were given of snow crab spatial distribution and biomass trends. Then, a series of 14 presentations reviewed the current state of knowledge, data availability, and methodological approaches relating to the various potential mechanisms for regulating recruitment throughout the snow crab life cycle. Mechanisms and life history stages reviewed included mating systems, egg production, larval supply and dispersal, settlement, distribution and mortality of early benthic stages, as well as recruitment indices based on cannibalism, predator stomachs, and surveys. Potential mechanisms that affect older juveniles and adolescents were also addressed, including effects of variable growth and condition, as well as mortality due to disease and other fisheries.

It was apparent that there are two major issues that would have to be resolved to develop an understanding of the causes of recruitment variability. The first issue relates to defining biological units and their boundaries throughout Atlantic Canada. This aspect would focus on larval stages in relation to pelagic ecosystem processes to determine whether advection maintains extensive zonal mixing and a single Atlantic Canadian metapopulation, or whether there are strong retention mechanisms that maintain local settlement and recruitment and (possibly) multiple biological units. Such an investigation is necessary to evaluate the spatial scales over which recruitment processes operate. Conceivably egg production and larval supply in a given region or area may serve as 'sources' for Early Benthic Stage (EBS) 'sinks' in downstream areas. This investigation would be closely linked with studies of benthic stages in that it would be essential to determine relationships of larval distribution and anundance patterns with those of mature females (egg production) and EBS's (settlement). These comparative studies would also be crucial to determining the critical stage at which year class strength is established.

The second major issue related to the relative roles of density dependent versus independent effects on settlement and initial benthic year-class strength as well as on subsequent survival of older benthic stages. The high level of interest in resolving these issues implied considerable potential for zonally collaborative multidisciplinary approaches.

Discussion:
The brief discussion focused on questions about how the workshop helped to focus plans for future research. The key point is that it documented that status indices were not universally applicable, and explanations for the differences among regions needed to be understood more completely. It was also noted that if the strategic research funding were secured, some results would become available within just a couple of years. However, other parts would require as much as six years before complete results would be ready.

5. REGIONAL ASSESSMENT METHODOLOGIES

- **Dawe, E and D. Taylor**

Methodology for estimation of Newfoundland and Labrador snow crab biomass indices and resource status from multispecies surveys and the analysis of commercial fishery data.

a) Multispecies Surveys (E. Dawe)

'Stock' Area:

Div. 2J3KLNO (fall)
Div. 3PsLNO (spring)

Biological data collected:

Catch numbers and weight (kg) by sex
Carapace width, shell condition, incidence of Bitter Crab Disease (BCD) from external observation
Chela height (males)
Maturity, egg clutch fullness, egg stage (females)

Grouping the biological data:

A schematic model of snow crab recruitment was followed in assigning individuals to population components for subsequent analysis. Based on this model, data were grouped into classes for each of three biological variables:

i) Carapace Width (CW) – based on growth per moult data, three main size groups were established: legal-sized crabs (≥95 mm CW); Sub-legal 1, those which would achieve legal size after one moult (76-94 mm CW); and Sub-legal 2, those which would achieve legal size after two moults (60-75 mm CW). All other males were pooled into a category of small males (<60 mm CW). This group was divided into two groups (40-59 mm CW and <40 mm CW) to describe the effect of size on incidence of BCD from fall bottom trawl surveys.

ii) Chela Allometry – males develop enlarged chelae when they undergo a final moult. This may occur at any size larger than about 40 mm CW. Therefore only males with small chelae will continue to moult and subsequently recruit to the fishery. A model which separates two 'clouds' of chela height on carapace width data ($CW = 0.0806CH^{1.1999}$) was applied to classify each individual as either large-clawed or small-clawed.

iii) Shell Hardness – males that undergo their terminal moult in the spring will remain new-shelled throughout the fishery season of that year and will not be fully hardened until the following year. For practical purposes new-shelled legal-sized crabs are considered to be part of the exploitable biomass, although it is recognised that they are not retained by the fishery early in the

season. It is assumed that all males with small chelae remain new-shelled between moults. In reality, however, an annually variable proportion of small-clawed males will not moult in any given year ('skip moulters') and so will develop 'older shells' between moults. For each year that a crab skips a moult, it's eventual recruitment is delayed by a year.

Environmental data utilised:

CTD and meteorological data are collected with each set.
An Oceanographic Review has been provided (E. Colbourne) at recent shellfish RAPs, before species assessments begin. Temperature, salinity and density data from spring and fall multispecies surveys are extensively used.

Assessment Methodology:

Survey method and time series

The Newfoundland Region adopted the Campelen 1800 trawl, with rockhopper footgear, as its standard survey bottom trawl in 1995. The Campelen fall series began in 1995 whereas the spring series began in 1996; initially, snow crab was sampled during spring only in Div. 3Ps, the only division not also surveyed in fall.

The Campelen 1800 is a shrimp trawl and so has relatively small mesh, but mesh size changes throughout the trawl, generally decreasing from mouth to codend. Codend mesh size is 27 mm stretched. Beginning in fall 1999 (for only part of that survey) a larval bag has been affixed to the outside of the trawl in front of the codend, to sample small shrimp and crabs that escape through the main trawl mesh. Larval bags are being used for all sets of both spring and fall surveys in 2000.

Each trawl set involves towing the trawl along bottom for 15 min. at 3.0 knots, a distance of 0.75 nm. Trawl performance is constantly monitored using SCANMAR. All commercial species of finfish and shellfish are sampled from each set. The Roxanne Seabed Classification System collects data on sediment type along the cruise track.

Survey design:

The survey utilises a stratified-random sampling scheme. Stratification is primarily by depth and, within each depth interval, by area. Sets are apportioned among the strata in direct proportion to stratum area, with the constraint of ensuring at least two sets per stratum for statistical purposes (i.e. to enable variance estimation). Set locations within strata are randomly assigned, also for statistical purposes.

The stratified-random survey design was developed in response to the very uneven spatial distribution of most species, which can result in large sampling biases, especially under systematic sampling schemes. Stratified- random sampling allows for relatively unbiased estimation of the precision of mean abundance and biomass estimates. Depth stratification is based on relationships

of distribution of most of the major species with depth and it facilitates investigation of oceanographic or bathymetric effects. Area stratification further ensures that sampling is well dispersed across the entire survey area. Area stratification is nested within NAFO Divisions. A more thorough evaluation of this survey scheme has been provided by Doubleday, 1981 (NAFO Sci. Coun. Studies 2; 7-55).

Survey biomass estimation

Minimum trawlable biomass estimates are generated using STRAP (Smith and Somerton 1981) separately for legal-sized males and for mature females. Biomass estimates for each group are generated by NAFO Division using 1995-99 fall survey data for Div. 2J3KLNO and using 1996-99 spring survey data for Div. 3Ps. Biomass estimates are interpreted qualitatively because the catchability of the survey trawl for snow crab is unknown, but is known to be less than 1. Estimates for legal-sized males are considered to represent residual (post-fishery) biomass levels, although a small proportion of the annual catch was taken during the October-December survey period in each year.

Spring versus fall survey biomass estimates

Biomass estimates of legal-sized males for NAFO Div. 3Ps from spring pre-fishery surveys during 1996-99 are highly unreliable, as indicated by broad confidence intervals, especially in 1999 (±79%). Such poor estimates are probably largely due to the highly aggregated biomass as also noted for Div. 3NO from the fall surveys. The spring biomass index of legal-sized crabs for 1997 was lower than both the 1996 biomass estimate and the 1997 catch by a factor of 4. It almost doubled in 1998, and further increased by 19% in 1999, but remained unrealistically low. Such low estimates probably reflect lower catchability in spring than fall, associated with distribution and behaviour patterns during the spring moulting season. Therefore no advice is provided based on spring multispecies surveys.

Projection of Div. 2J3KLNO exploitable biomass

An initial exploitable biomass index is calculated for the following year from each yearly set of Div. 2J3KLNO fall survey data. This index is comprised of three components:

i) Standing stock component; Survey biomass of 'residual' large-clawed (terminally moulted) legal-sized (>94 mm) males.
ii) Growth component; Biomass calculated after applying a growth increment of 19 mm to 'residual' legal-sized (>94 mm) small-clawed males.
iii) Recruitment component; Biomass calculated after applying a 19 mm growth increment to prerecruits (76-94 mm small-clawed males).

Projection of annual exploitable biomass indices does not account for annual variability in natural mortality, in proportion of small-clawed males (both legal-

sized and prerecruit) that do not moult in the following spring (skip-moulters), or in size-at-terminal moult.

Relative exploitation index

The ratio of catch to the exploitable biomass index is used as an index of relative exploitation. It does not estimate absolute exploitation rate, because catchability of the survey trawl is less than 1, so exploitable biomass is underestimated. However this ratio does indicate annual changes in exploitation; for example it showed that the exploitation rate had been stable during 1997-98, not exceeding 0.40, and increased in 1999, to a maximum of 0.53.

Trends in size distributions

The survey trawl samples virtually the entire size range, such that annual changes in abundance of small males provide insight into long term recruitment expectations. To examine size composition of males, carapace widths were grouped into 3 mm intervals and adjusted up to total population abundance. Each size interval is partitioned by claw type.

Advice Provided (Div. 2J3KLNO):

- Change in spatial distribution of commercial males as well as all other population components
- Change in fall residual biomass level
- Change in exploitation rate
- Projected change in recruitment and exploitable biomass
- Long-term recruitment prospects based on changes in relative abundance of small males
- Changes in biomass of mature females
- Changes in the physical environment and in distribution and prevalence of disease as well as potential implications of such changes on future recruitment
- Sources of uncertainty

Discussion:

Questions posed included:

- Was the purpose of the observers to control high-grading or just to quantify it? - Both
- Are the observer data on soft-shell rates used to close fisheries? - Yes. Although there is not fixed criterion, functionally closures are considered when soft-shell rates reach around 20%.
- With regard to logbook format and function - There is not a single universal logbook for all fisheries in Newfoundland Region, but all the logbooks capture much the same information. The reporting of position is variable, and for different fisheries has to trade off accuracy and precision. It was also noted that the differences among provinces in the form and content of their logbooks presents some problems for uses of the data they contain. There were several potential problems suggested with self-reporting logbooks, but it was agreed that logbooks were useful as general status indicators.
- It was also agreed that it would be useful for subsequent uses of the information, if Science had more input to allocation to observer coverage.

b) Commercial fishery data (D. Taylor)

Analysis of annual fishery performance within the Newfoundland and Labrador snow crab fishery is accomplished by utilising a number of tools. Of primary importance is analysis of logbook-generated catch/effort data. This is done on a large scale for NAFO divisions as well as for various fleet sectors within defined crab management areas. These analyses produce time-series that provide insights into long and short-term trends in the commercial abundance of snow crab. These data are augmented by information provided by two Index fisher programs and by biological sampling carried out by at-sea observers. Dockside monitoring of landings which is mandatory in Newfoundland and Labrador provides verification of fishers' estimated landings and also provides information on disease and soft-shell occurrence.

Discussion (on both talks):

- What is the role of the trap survey in the assessment? The trap survey is restricted to White Bay and part of 3K, with an emphasis on coverage inshore of the trawl survey. Because of limited distribution it is not used as an abundance indicator, but has other specialized functions.
- With regard to how the TAC is established from the assessment, there is no fixed algorithm linking TAC to survey biomass estimates. The projected biomass is allocated across areas, and exploitation rates between 40 and 53% have been functionally applied in recent years. The expansion of area of the fishery and number of participants has made system quota setting relative to survey biomass not very systematic. Also, when survey biomass indices have declined, cuts have been applied geographically across the board, even when biomass changes were not the same in all parts of the surveyed areas. The lack of correspondence between trawl CPUE and industry CPUE in the same areas have meant that surveys have sometimes had low credibility. Small clawed crab above the minimum carapace size are included in the population biomass estimate because they will have hardened by the end of the year. This is a difference from Gulf Region, where only large clawed crabs are included in the biomass estimate contributing to the TAC calculation.
- It was noted that in Newfoundland they only estimate total population size, so standard STRAP calculations are sufficient without dealing with complexities what part of the survey area corresponded to what part of the fishable biomass.
- In response to the observation that a fixed net opening is assumed in the estimation algorithims, it was noted that net performance is monitored with SCANMAR, so this assumption can be checked regularly.
- Are there problems with integrating the different information sources, and are you looking to emphasize one of them? No there are efforts to improve all the information sources, such as correcting CPUE for soak time, and standardization of indices.
- How are skip moulters handled in the trawlable biomass estimates? At present there is no provision for them. It is a concern, but we don't know how big a problem it is. Much of the inaccuracies in biomass projections could be from skip moulters, but also could be from crabs which moult but suffer excessive mortality. Further research may help clarify this matter.

As a summary of the long discussion, it was noted that trends in survey and CPUE indices DO influence direction of change TAC but there is no fixed algorithm for relating trends in indices to change in TAC. Once a change in TAC is made then it is applied at the same rate inshore and offshore but does vary north to south.

- **Moriyasu, M. and M. Hébert**

Methodology of data analysis used for the stock assessment for the southern Gulf of St. Lawrence and Eastern Nova Scotia.

Stock assessment as been done for 5 stocks in the SGS (total surface of fisheries at 78,000 km^2 total landings at 18,500 t with 340 licenses in 2000) and 6 stocks in the ENS (total surface of fisheries at 225,000 km^2, total landings at 9,900 t with 250 licenses in 2000).

Three sources of information used for these fisheries are as follows:

(1) Commercial sampling: Mandatory logbooks are used for assessing CPUE level, fishing effort and landings and their geographic distributions. The information provided by fishers comprises of fishing data, trap positions, depth, gear type, estimated catch, landings (certified by DMP weighmasters), number of trap hauls and soak time (hr). At-sea observer and at-port sampling programs are also in place since 1990 in the SGS and 1998 in the ENS. The level of observer coverage varied from 5% (1990) to 15% (2000) in the SGS and from 5% (1998) to 10% (2000) in the ENS for the purposes of in-season fishery monitoring (e.g. CPUE, mesh size), white crab and high-grading monitoring.

(2) Biological Survey: Annual trawl sampling has been conducted in Baie des Chaleurs since 1998 to study reproductive biology. Trap surveys are conducted on as needed basis. Annual tagging studies have been conducted since 1996 in SGS & ENS.

(3) Fishery Independent Survey: Annual bottom trawl survey has been conducted since 1989 in the SGS and 1997 in the ENS using a Bigoudin *Nephrops* trawl net, stretched wing width at 20m equipped with Netmind® sensors. The survey is conducted in July-September in the SGS at 275 stations and in May-July in the ENS at 320 stations. During the survey, the following measurements and observations are made on all crabs caught: sex, CW, ChH, carapace condition and hardness, missing appendages for both sexes and AW, gonad colour, presence/absence of eggs and egg colour for females, and by-catch species. Bottom water temperature, sediment type, depth were recorded at each station, but not incorporated into stock assessment process. The direct biomass estimate is considered as minimum trawlable and used for setting a quota on an annual basis. The long-term stock trend is forecast based on the abundance of R-3, R-3 and R-1 as well as size-frequency distributions. In general, scientific advice is given at the RAP meeting after a minimum of 2-3 consultations with industry participants and managers.

Discussion:

- Does Science have any input to observer deployment? Science has no control over allocation, but allocation is random so the results can be used as representative.
- Are observers assigned to a particular area throughout the year? Each observer gets some minimum number of trips, but they can be anywhere in the fishery.
- When areas are closed because of high white crab and effort is displaced, does it concentrate elsewhere? Fishing is concentrated so local depletion is the rule and closures actually disperse effort.

- The softshell closures are to protect crab during a period of transition, but if closure are by grid square effort is continued to be applied, and likely increases on hardshell areas. Does this result in increased exploitation on grids with good populations? The main effect of the closure mechanism is that it gives an incentive to fish early. Prior to fishery openings Science gives warnings of where problems with white crab is expected. Both managers and industry use this information in setting management plans and fishing strategies, respectively.
- Once an area is closed for white crab is it closed for the season? Yes.
- During the survey, is presence of untrawlable bottom more of a problem in eastern Nova Scotia (eNS)? Yes it is. In eNS, all areas with bathymetry <70 m are excluded from biomass estimate area, and we don't know how that affects accuracy of the survey estimate.
- Does the percent soft-shell crab take account of commercial size limits? The percent soft is in numbers of crab, regardless of size.
- If a fixed station survey design is used how do it take account of the likelihood that crab distribution may be changing? There are some inconsistencies between survey and commercial indicators of stock status, and these can be informative. There is some movement of crab, and it is interesting to both Science and industry. Survey costs are financed by 98% by industry Southern Gulf and 90% for eNS, and they take great interest in the survey results.
- How does precision of survey biomass estimates compare between the two areas? The confidence interval for the whole area is +-35% with kriging. In eNS where biomass is low, the CI can be +- 50%. These uncertainties also have implications for the relationship of target exploitation rate to actual biomass.
- What was industry's opinion regarding the assessment conclusion that there was risk of an increase in exploitation rate when the last recruitment pulse was coming in and prompting higher incidence in white crab? From the management perspective there was also a big accumulation of mossy old crab to fish out in 1999 and this was prior to the big recruitment pulse. There was also a good abundance of crab from the 94/95 cohorts that would die out in 99-2001 anyway, so fishing opportunities could be provided without concerns about excessive exploitation rate.
- If the management response was to increase exploitation on old crab to keep exploitation on new legal hard-shell males around the target, is there any evidence from observers and dockside monitoring that they were actually going after the old crab? The percentage of mossy crab was over 60%, and trends an sea and port sampling converged, so managers were satisfied that harvesting did shift onto old, mossy crab.

- **Dufour, R. and B. Sainte-Marie**

Stock assessment methodology in the northern Gulf and Estuary of the St. Lawrence

Estuary and northern Gulf of St. Lawrence snow crab are assessed by DFO, Laurentian Region, since 1983. The fishery started at the end of the sixties and landings remained at a low level until the beginning of the eighties when it grew rapidly and reached a high in 1985 (5,818 t) and 1995 (7,247 t).

Two main strategies are used for stock assessment. Firstly, the annual status of the resource is addressed by estimation of punctual indices such as abundance, size and condition of all groups of crab (males-females, mature-immature and commercial-non

commercial crab) in a given area. Then, indices are compiled by time and space and analysed to give the actual status of the resource. The outlook on a short and medium term basis is given to fishery managers and industry by means of a Stock Status Report (SSR), DFO Research Documents and meetings where results of the analysis are explained in detail.

Four main tools are used to assess the stocks:

(1) Commercial fishery log books from fishermen and sale slips data usually from plants are compiled by DFO sector. Then data validation and analysis are done by MLI Sciences. Main indicators coming from this information are trends in catches, CPUE and fishing effort.

(2) At sea and port samples are also taken regularly during the fishing operations. Size and condition of the crabs as well as immediate prerecruits are recorded and entered in the system for analysis and production of indices.

(3) Trawl research suveys using a 3 meter beam trawl (20 mm mesh size in the codend) are done sparsely on the territory where bottom conditions permit. However, two areas (north shore of the Estuary in area 17 and Bay St. Marguerite close to Seven Islands) have been covered annually since 1994 and 1989 respectively. Other areas in the northern gulf have been covered when needed since 1990. Those surveys give long-term abundance indices on prerecruits (6-94 mm CW), recruits and residual crabs (males 95 mm to maximum size). Legal and sublegal crab size and condition indices are also calculated for males and females. Other indices as sex ratio and reproductive success as indicated by sperm storage are also yielded from this kind of survey.

(4) Trap research surveys done with the fishermen were started in area 16 in 1994 and have spread to cover all areas in the northern Gulf by 1999. Commercial traps are used on a systematic sampling design (transects) to yield short-term abundance indices on immediate prerecruits (78-94 mm CW), recruits and residual crabs. Crab size and condition indices of males are also calculated. Fundamental and applied research findings are incorporated to the assessment as needed and when it can be done.

A three year comparative index and analytical index are developed thereafter with all available information allowing a deeper analysis of the status of the different stocks assessed. Short and long-term recommendations are given to the managers and industry people as a science basis to the discussion on TAC and conservation measures to be taken.

Discussion:

- Category V crabs are excluded from the biomass estimates. Is this because they are considered uncatchable? If they are caught then they are used in coming up with the standing biomass. However, they are forecast ahead, because most will die during the winter anyway.
- How long does the trap survey take to complete? 2 weeks. If the weather changes will survey catch rates change? No, the crab catch rates are not as vulnerable to weather as catch rates of lobster - if the survey is completed in one or two weeks

weather should not cause much of a difference. Crabs are also deeper than lobster so surface conditions are less influential. For the industry survey there is 100% observers and fixed soak times.

- There is a temporary seasonal fishery in 13. How are data from that fishery used in the assessment? Science hasn't seen much data. There were few fishers and little catch, so right now there are no plans to do much with information from that fishery.
- Because indices are considered relative rather than absolute, how does one know when limits are being pushed with exploitation? The harvest rate is considered very conservative so pushing limits of exploitation is not an issue. Also using 2-3 indices introduces some margin of safety. Moreover, the indices are interpreted in terms of where the stock is in its abundance cycle. Also the relative CPUE is correlated with absolute indices in the area where absolute values were available.
- Past collapses have also provided information about danger signals that are used to interpret current indices.
- It was also noted that relative indices are used widely in assessments of other stocks. The big concern is the danger of inconsistent bias over time in relative indices, such as area occupied changing with abundance in a fixed station survey design.

6. REGIONAL MANAGEMENT APPROACHES (Regional Fisheries Managers)

Written summaries of management approaches were not provided for the individual regions. These are covered fully in the written Management Plans available for Snow Crab in each Region.

A) Laurentian Region

Discussion:
None

B) Southern Gulf

Discussion:
It was reported that a minimum mesh size for traps was only in place for Area 12, where it is 75 mm.

C) Newfoundland

Discussion:
There was discussion about the idea that white crab is viewed as an economic measure and not a conservation concern. In practice Newfoundland management encourages industry to return softshell and white crab to waters. Industry will accept white crab but not soft crab, at least at some times. A two-price system was tried in 1997 and it was found to cause lots of high-grading. In response processors increased tolerance of white crab to 20% and that has helped reduce high-grading.

D) Nova Scotia
Written Summary not

Discussion:
Because of the time when the fishery began to build up here, the high biomass phase was missed. It was proposed that the stock had already peaked in 1997 yet managers are allowing more fishermen in and could triple effort by 2001. This may be creating serious problems. If crab show cyclic patterns the stock could be headed downward. Correspondingly, if the stock is considered opportunistic anyway, now that temperature may be warming and crab declining, what should be done; exploit it particularly heavily before it is lost? Managers reported that the permanent license holders think this stock was hit too hard, whereas temporary fisheries think that exploitation was too late. First Nations fishers have 1000 t out of 5600 t overall.

7. SPECIFIC SCIENCE ISSUES

a) Stock definition: Biological and management definitions

- **Sévigny, J.-M.**

Snow crab population genetic structure in the Northwest Atlantic: discrete stocks or metapopulation.

The stock structure of snow crab in the Northwest Atlantic was investigated using morphometric and genetic approaches. Adult males measuring between 70 – 120 mm CW were collected at 7 sites from Greenland to east Cape Breton on the Atlantic coast and at 11 sites in the Gulf of St. Lawrence. In addition, mt-DNA analyses were carried out on individuals belonging to different cohorts sampled in Baie Sainte-Marguerite, northwest Gulf of St. Lawrence, in an attempt to estimate the importance of temporal variation in the genetic characteristics. Results to date have revealed that important differences in morphometric and genetic characteristics occur not only over the large scale of the Northwest Atlantic, but often between sites that are geographically close to each other. This heterogeneity occurs despite the potentially high dispersal of the species and does not translate into obvious geographic organisation and can, at least partly, be attributed to the presence of different cohorts in the sampled adult populations. Indeed, important genetic differences were also detected among some cohorts within Baie Sainte-Marguerite. It is hypothesised that the genetic heterogeneity observed in snow crab result from a small effective population size. Additional work using the recently developed microsatellite DNA markers is needed to address this issue.

Discussion:
It will be necessary to consider and clarify the links between effective population size and the biologically meaningful exploitation rate of the fishery. If only certain categories of males and females can supply enough eggs or sperm to matter, how do we think about exploitation rate on the population as a whole, and on that portion specifically?

In this context, it was noted that the phenomenon of effective populations may be very different from typical pairing of one male and female. The relative contribution of individuals has to do with timing of availability of spawners, as well as numbers. Some participants argued that the population needs lots of spawners annually, even if not all of them participate in breeding every year, because very different samples of

spawners survive from year to year. With regard to whether effective population size can be related to the breadth of the spawning window, it was agreed that it can be but does not have to be.

If these genetic clusters "seem" to be like population units, they seem too numerous to be a basis for feasible management. Would the morphology be a better way to identify management units? Morphological traits will allow you to find stocks also, but in a different way. It is very hard to imagine that the Atlantic snow crab really have so many small independent population units that management must be structured around.

b) Distribution and movement of snow crab

- **E. Colburne, D. Orr and E. Dawe**

Distribution of Newfoundland and Labrador snow crab in relation to bottom temperature from fall 1995-99 multispecies surveys.

Recent trends in bottom temperatures and anomalies in NAFO Divisions 2J3KLNO were presented together with the spatial distribution of snow crab catches and abundance. The bottom temperature data presented were obtained from the fall surveys from 1990 to 1999 and crab catch data were obtained from the fall multispecies surveys from 1995 to 1999. Variations in the near-bottom thermal habitat were examined by calculating the areal extent of the bottom covered with water in different temperature ranges. The analysis revealed a significant shift in the thermal habitat in the region, from the cold sub-zero °C conditions of the early 1990s to a relatively warmer environment of the late 1990s. During this time period the area of sub-zero °C water covering the bottom on all major banks during the fall in the Newfoundland Region had decreased to near 0%, with a very small area of sub-zero °C water restricted to the deeper portions of the Avalon Channel. The time series of the average bottom temperature for each NAFO Division during the fall showed colder than normal conditions during the first half of the 1990s reaching near record low values during 1993. Since 1995 however they have increased to above average values reaching record high values during 1999 in some areas.

Spatial maps of the numbers of snow crab per Campelen trawl set were displayed as expanding symbols with the temperature contours from 1995 to 1999 for the fall multispecies surveys. The mean number of crab per set in 1°C-temperature bins was also computed for each year. In Div. 3L the total number of crabs caught per set during each year was widely distributed across the available temperature range from sub-zero °C in water depth <200 m to above 3°C in the continental slope regions. In Div. 3NO crab catches were mainly restricted to the slope regions with temperatures in the 2-4°C range. Virtually no crabs were caught in water depths less than 100 m where the temperature often exceeds 3°C in these southern regions. In general, the total number of crabs per set in all temperature ranges showed a significant decrease beginning in 1997 with 1999 showing the lowest catch rates. An examination of the number per set of small males with carapace width less than 60 mm in 1°C-temperature bins showed some indication of a preference for temperatures less than 1°C, particularly during 1997 to 1999.

In Divisions 2J and 3K the total number of crabs caught per set was also distributed across the available temperature range of –1 to 4°C. However, along the continental slopes in the temperature range of 3-4°C crab catches were almost all zero particularly in Div. 3K. In general, the total number of crabs caught per set in all temperature ranges in 3K shows a downward trend from 1995 to 1999 and in Div. 2J the number caught per set showed a marginal increase from 1995 to 1998 but decreased again over all temperature bins during 1999.

A new sampling program for early benthic stage (EBS) snow crab on the Northeast Newfoundland Shelf and Grand Bank-St.Pierre Bank (NAFO Div. 2J3KLNOPs) was also described. This program was initiated in 1999, in conjunction with ongoing multispecies bottom trawl surveys. It involves the attachment of a 'larval bag', with 1 sq. m mouth opening, to the Campelen 1800 survey trawl at a position in front of the codend to sample the mesh escapement. Although initiated as part of northern shrimp (*Pandalus borealis*) investigations, this device has proven effective in sampling EBS snow crab. It was used for only a portion of the fall Div. 2J3KLNO survey (i.e. Div. 2J3K), but for all of the spring 2000 Div. 3LNOPs survey. Very small EBS's that were not represented in the main trawl codend catches predominated the larval bag catches, with a sharp mode at 7 mm in fall 1999 and with two equally frequent modes at 5 mm and 7 mm in spring 2000. Largest fall 1999 Div. 2J3K larval bag catches were from sets nearest the coast in coldest water (-0.5 to 1 degree C) and catch was inversely correlated with bottom temperature. A similar but less clear trend was apparent in Div 3LNOPs during spring 2000.

Discussion:
What are the retention mechanisms in that area, if any? None are known, but there are consistent anomalies of cold water temperatures in an area along White Bay, relative to long term average conditions. There could be a recirculation mechanism in that one key area.

It was noted that if the thermal habitat of snow crab covers the range of –1 to +4 °C, then essentially all the marine habitat in Newfoundland is suitable habitat. Perhaps the relevant thermal habitat for the Newfoundland shelf may be habitat for early settlement larvae.

- **Surette, T. and M. Moriyasu**

Distribution of modeled moult and maturity groups of snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence.

Using 1999 stock assessment trawl data, a moult-group classification model was applied to size frequency histograms of adolescent males and immature females to estimate densities by sample site. This model assumes; 1) that moult-groups are normally distributed according to carapace width; 2) that the means of these distributions follow a linear growth model and 3) that the variance increases with size. The estimation of the parameters of this model used an interactive procedure to minimise the residual sum of squares (RSS) function.

A brief descriptive overview of the distribution of male and female moult-group as well as male (immature, adult) and female (adolescent, preprimiparous, primiparous, multiparous, senile) maturity groups was given.

Discussion:
It was noted that some distributions presented are very interesting. Crab that are skip moulters, in particular, seemed to have spatial distributions that are especially different from the other types of crab. However, it was also stressed that the pattern was documented in one year, and there is a need to look at many more. Nonetheless, it was suggested that protecting spawning population on scale of the entire southern Gulf is too huge a task, and it may be necessary to be working on finer geographic scales.

It was also observed that the breadths of the modes are broad and may be pooling a lot of local variation. This may obscure certain patterns of biological importance. Also from year to year the populations could have a lot of different signals that need to be partitioned.

- **Savoie, L. and M. Biron**

Movement of snow crab in the Gulf of St. Lawrence and on the Scotian shelf by means of tag/recapture study.

The objective is to study adult snow crab movement over a long-term data time-series (covering 1 or more cycles of 10 years) in the Gulf of St. Lawrence and on the Scotian Shelf. On a finer scale, the interest is to look at local movement, movement between biological units and movement between management areas, as well as the relationship between the Magdallen Shallow and the Scotian Shelf. Preliminary results indicate short-range movement with a hand full of exceptions. Some regions (Western Cape Breton, Northern ENS) show more movement activity than others (South Western Gulf) bringing more uncertainty to their stock evaluation. Another observation is that crabs do not follow management lines. Some of the limitations of tag-recapture methods are that: it gives only point A (release site) and point B (recapture site), and not the real movement in between these two points; the recaptures are limited to fishing locations in any given year; the tag return rate is unknown; and the mortality rate (natural and tagging manipulation induced) is unknown.

Discussion:
It was observed that the tagging program had low returns from the commercial fishery, suggesting the program may not be getting too much cooperation. In general one expects return rates of 30% at best. Possible problems suggested were that the rewards were only a hat or a clipboard, providing little incentive to return tags, and perhaps harvesters don't want to report tags if they think that the management boundaries could be at risk from the results.

All the crabs taken are adults but why spend effort assigning them to type? It's already known that harvesters and processors don't like to take soft-shells. In response it was repeated that a key objective of the project was to test the Ho of movement as F(density), and as a result to try to align harvest rate with changes in density.

If the tagging results really do demonstrate that preferred habitat occurs in the southern Gulf, what are the characteristics that make it prime habitat? At this time we simply don't know.

There was some discussion of potential biases in tag returns, concluding that the results were good enough for showing local populations as units that can be managed. This is particularly relevant to the issue of whether or not separate biological units occur in eastern and western portions of southern Gulf. Management continues to manage on the basis of historical units, but at some point the units need to be reviewed in light of the new information needs.

c) Crab recruitment mechanisms

- **Sainte-Marie, B. and R. Dufour**

Periodic recruitment patterns in snow crab and the potential underlying mechanisms.

Although it is obvious that snow crab recruitment occurs in pulses, the pattern and the factors underlying variability are uncertain. A uniquely long time series of benthic trawl surveys exists for the northwest Gulf of St. Lawrence, spanning 1982 to 2000. A growth-model based retrospective analysis of size structure for snow crab in this area indicates that the population has been influenced since the early 1970s by 3 sequences of low and of high recruitment, with each sequence lasting about a decade. This cycle is apparent in the St. Lawrence Estuary as well, albeit the time series is shorter, and it causes pronounced oscillations in the abundance, size, shell condition and proportion of adolescent males represented in the legal-size component of the population which are mirrored in fishery performance. Additionally, this cycle entrains large interannual variations in the ratio of pubescent (primiparous) females to adult males and smaller variations in the ratio of multiparous females to adult males. Recruitment troughs are generated early in ontogeny and therefore reflect reductions in postlarval supply or high postsettlement mortality. Variability in postlarval supply may be linked to changes in the female spawning biomass (egg production), while postsettlement mortality may arise from density-dependent cannibalism. The temporal scales of periodic recruitment are not as well defined in other snow crab fishing areas but on the Scotian Shelf they appear to be longer and possibly more sporadic. There, snow crab recruitment may vary more in relation to temperature-mediated expansions and contractions of habitat.

Discussion:

With regard to Elner's Ho of negative effects of larger pre-recruit crabs on smaller pre-recruits, don't the spatial difference in occurrence makes this Ho untenable? The experimental work suggests that crabs greater than about 50 mm can't handle small ones as predators anyway, even if there were to overlap in spatial distribution.

Why is there such a weak relationship between CPUE and biomass? This suggests fishers aren't changing fishing patterns in response to changing abundance. It was suggested that there is hypersaturation of CPUE in the spring fishery when males are highly aggregated, which would obscure any density responses.

With regard to post-larval supply, the Figure presented may be a weak test of relationships because the supply of larval and post-larvae to an area may not be a local phenomenon. There was agreement that it was a weak test, but because of the patterns, we should not ready to eliminate the hypothesis yet.

The observed patterns in the mean size data may be more readily interpreted as evidence of high-grading. This could be true but also could be differences in efficiency of the two gears. Moreover, the same pattern is present in data from trap surveys where there is no high-grading.

With regard to the difference between 89/90 and 99/00, should a manager be alarmed that a lot of males have not reached commercial size with terminal moult? That depends on why it happened. If the maturation at small size is the cold water-growth relationship not much that can be done. However, if it were a fishery effect, (which the presenters considered unlikely) it would require adjustments to management strategies. Before those are considered though, it is necessary to look at a much wider range of temperatures.

Looking at the recent data on high frequency of maturation below legal size, in the short-term if the effect is real, there will be great loss of yield. This may be a major immediate management concern. However the long-term consequences of different size composition of male breeding population, which may endure a much longer time will be the more important effect. In the short term the recruitment pulse is large enough that the portion that will be above legal size at maturity will still produce a good fishery, but still there are even short-term problems. For example, for the first time management had fishers charged with bringing in undersized adult crab.

If we make a biomass estimate for harvest using the current data, will we see effects of this increase in maturation at sublegal size? YES

If there are so many males maturing below 95mm, should we be asking if 95mm is the proper cut off for legal retention?

These results suggest we have a mechanism for terminating a pulse of good recruitment. Is it possible to explain the mechanism(s) that account for the beginning of the periodicity? The mechanism may be that there is always potential for good recruitment, and it is the cannibalism that is periodic. This means that mechanisms that cause to period of cannibalism to vary will cause the length of intervals of good or poor recruitment to vary as well.

An alternate Ho for the recruitment pulses is that there are two kinds of females. If primiparous and multiparous females do not contribute equally to larval supply, then variation their ratios can also cause cyclic pattern of recruitment. The researchers have been looking at value of the two groups and there are differences, but the results are not ready to support too broad an interpretation.

- **Taylor, D.**

Inshore trapping/trawling surveys as indicators of recruitment trends, BCD prevalence and commercial abundance in Newfoundland.

Annual time-series research cruises have been conducted at 3 locations (Bonavista Bay, Conception Bay and 3-40 n. mi. NE of St. John's) since 1979. Until 1996 the principal survey tools were baited traps, both commercial and small-meshed. In 1996 an additional sampling tool, a modified Yankee #36 shrimp trawl has also been utilised. The current strategy is to sample all randomly selected stations with each gear type in order to obtain comparative data on commercial abundance, sex ratios, BCD prevalence and recruitment trends.

Discussion:

Isn't there a North-South trend in bitter crab disease? Doesn't seem that way in the data. There are very few reports off the Avalon Peninsula; reports are mostly from 3K offshore.

It was suggested that the reason observers are seeing more in Conception Bay than other sites may be seasonality of the disease, and we aren't doing full seasonal surveys in most places. Bitter crab disease (or at least visible symptoms) is more widespread in fall and that matches the timing of the Conception Bay survey.

At what stage does it show up? It can show up at all size groups and sexes about 5 months after moulting. Researchers find the symptoms more frequently than fishers do because researchers are looking for it all the time. . The first obvious signs are a white heart where the parasite is based, and fishers rarely open crabs to examining the heart.

d) Conservation of reproductive potential.

- **Sainte-Marie, B.**

Sexual competition, male allocation strategies, and reproductive success of female snow crab.

In snow crab, it is often assumed that reproductive output is sustained for exploited populations due to the prohibition to land females, the capability of females to store sperm, and the protection of a large component of the adult male population (those sublegal). However, recent investigations in collaboration with A. Rondeau, J.-M. Sévigny and N. Urbani have revealed intricacies of the snow crab mating system that may invalidate this assumption. Laboratory experiments indicate that the mating of pubescent females is highly competitive. Large adult males may play a disproportionately important role in reproduction because they can outcompete smaller males and can adjust guard time and sperm allocation to sociosexual context, thereby maximising the number of females they mate during a breeding season. Multiple mating by dominant males can lead to sperm depletion, the extent of which is also a factor in the sperm allocation strategy. In extreme cases, a small number of large males may monopolise many females and inseminate them insufficiently, causing sperm limitation and loss of egg production. There is field evidence that female sperm reserves and fecundity are inversely related to sex ratio and that large

adult males in exploited populations do not currently reach levels of sperm repletion seen in prefishery times or contemporaneously in an unexploited population. Therefore, one consequence of intense exploitation on a population may be reproductive over-exertion for the surviving large adult males leading to sperm limitation, rather than a large shift in the burden of reproduction towards smaller adult males that would favour sustained egg production. More research is needed to evaluate to what degree sperm limitation is a problem in exploited populations, but for the time being consideration of sex ratios, abundance of large adult males relative to receptive females, and female reproductive success should be an integral part of the population assessments.

Discussion:
It was noted that in the US they consider it precautionary to leave older male crab in the populations, acknowledging their value to reproduction.

It was also reported that in all the exploited populations researchers have never gonad conditions like those illustrated for the oldest males of unexploited populations. The loss though, is very small when looking at an unexploited female population.

In exchange regarding the relationship between laboratory and field results, it was reported that experimental studies show that males whose spermatcheaca get severely depleted do not recover in a single year. However, in fall surveys off Newfoundland one often sees empty spermaetheacae but viable eggs in the females. The picture is very context specific, and at the bottom of the cycle on will see no sperm left. The important biological issue is whether females never got enough sperm to fertilize their eggs to begin with, or begin with enough but lose it.

The median size of male crab in the field study was 100 mm. How does this relate to size-specific exploitation? The large males compete for access to females, so if numbers of large adult males are reduced competition is also reduced. Larger males hence can still increase their proportional contribution to next generation.

If the sublegal males undergo highgrading what does that do? Consequences depend on the availability of large males.

- **Sainte-Marie, B.**

Ageing and changes in condition of male snow crab after the terminal moult.

It is widely accepted that male snow crabs undergo a terminal moult to adulthood. The appearance and condition of the shell and the body integrity of males gradually change after this last moult due to initial shell hardening, followed by fouling, destruction of chitin by bacteria, decalcification, and injury. Eventually the crabs die of senescence. Changes in shell condition (SC) are captured by a variety of arbitrary scales. In eastern Canada, one widely used scale rates snow crabs as clean-soft (post-moult, SC=1), clean-hard (SC=2), intermediate (SC=3), dirty-hard (SC=4) and dirty-soft (graveyard, SC=5). A 10 year tag-recapture study was conducted in the Saguenay Fjord, where there exists an isolated and commercially-unfished population of snow crab. This study indicates that shell condition is a good proxy of postmoult age and that males rarely live more than 7 years after terminal moult. Shell hardness

measured by durometer increases from SC1 to SC3, then declines until SC5. The number of missing limbs increases linearly with increasing SC.

Recently, the issue of 'old males' (SC4 and SC5) has been at the forefront of snow crab Industry and Management concerns. Reasons for this are (1) the widespread but unsubstantiated belief that there exists a negative relationship between biomass of old legal-size males and level of recruitment, and (2) the acute perception that resource is being wasted through natural mortality. From the industry perspective, prime adult males are SC2 and SC3, a condition that lasts only from about year-1 to year-3 after terminal moult. In many regions, a two-tier price system offers a strong incentive for passive and active high-grading by shell condition and number of missing limbs. Consequently, exploitation tends to concentrate on fewer cohorts than are represented in the commercial biomass and the proportion of old males in the residual biomass may sore when exploitation rates are high and recruitment is subsiding. From the perspective of conservation, adult males are in prime reproductive condition in SC3 and SC4 from about year-2 to year-4 after terminal moult. Therefore, there is a conflict between market demand and the goal of maintaining a healthy and diversified male spawning biomass. Some accumulation of old males and loss of biomass through senescence is inevitable if a significant portion of legal-size adult males is allowed to fulfil their reproductive potential. This is a desirable conservation objective.

Discussion:
The northern and southern Gulf are quite similar because researchers in both areas have concluded that crab III and IV produce the best spermatophore. Researchers in the southern Gulf also think that natural mortality is sudden after several years as an adult.

It was pointed out that there will also be less handling of white crab when if there is a lower TAC set in the first year of a big pulse of recruitment, which is also an advantage.

To understand clearly the recommendation is this paper, was it specifically to target more Stage IV crab when there was a strong recruitment? Yes, but that strategy is a hard sell.

e) Sources of mortality other than the crab fishery.

- **Dawe, E.**

A consideration of potential effects of bitter crab disease (BCD), discarding and shrimp trawling on Div. 2J3KLNO snow crab mortality.

The occurrence of new-shelled (recently moulted) crabs in the fall 1999 multispecies survey catches was lower than projected from the results of the previous year's survey. This could be due to a large proportion of sub-legal sized adolescent males having failed to moult ('skip moulting') in spring 1999 or (more likely) high mortality on recently moulted new-shelled legal-sized males. Sources of mortality that could selectively impact new-shelled crabs include BCD, discarding, and encounters with shrimp trawls.

BCD is caused by a dinoflagellate of the genus *Hematodinium* which is parasitic within in the haemolymph. It appears to be acquired during moulting because it has only been observed in new-shelled crabs and it is fatal to its host. It is recognisable externally in heavily parasitized crabs by abnormal pink or orange coloration of the dorsal carapace and joints of the walking legs, as well as an opaque white 'cooked' appearance of the ventral carapace. Incidence of BCD, based on external observation only, has been routinely noted during fall Div. 2J3KLNO, multispecies surveys since 1996. These data indicate that the disease occurred in Div.2J3KL in all years and was most prevalent in Div. 3K during 1996-98. It was has been virtually absent in Div. 3NO. It appears that the spatial distribution of BCD shifted northward during the past 3 years. Throughout Div. 2J3KL BCD has occurred in all size groups of males and in both immature and mature females. Prevalence has overall been highest in small males of 40-59 mm CW, with about 8% of that size group infected in Div. 3K during 1996-98. Inshore Div. 3K trap surveys during September have approximately corresponded with the peak season of incidence of BCD in Alaskan tanner crab (*Chionecetes bairdi*). These surveys indicate that in White Bay incidence of BCD has increased overall since 1995, and it appears to have progressed to deeper strata and larger males. In both White Bay and Notre Dame Bay incidence of BCD increased, and became most prevalent, in smallest males (<60 mm) in 1999. Although incidence of BCD has generally been low, it was noted that not all diseased crabs caught were likely to have been recognised by gross external features alone. Also, heavily parasitized crabs may not be representatively sampled by either traps or trawl. It was pointed out that moulting is frequent at small sizes and the disease is likely acquired at moulting, so the cumulative effect of this mortality across successive instars of a year-class may be substantial. Some of the spatial and annual trends in population abundance and distribution appeared to coincide with trends in prevalence of BCD.

Discarding of legal-sized crabs that are classified as 'soft' by industry could also account for selective mortality on new-shelled crabs. Data were presented to show that throughout much of the season about 20% of the catch is discarded and that this may exceed 40% in peak discard periods. The seasonal pattern and data from observer sampling indicate that these discards are mostly new-shelled crabs. It is felt that mortality on these discarded crabs is very high due to improper handling practices. It is, however, unclear why this mortality would have been much higher in 1999 than in the previous year.

The possibility that shrimp trawling causes significant snow crab mortality has been raised by crab fishers in northern areas (Div. 2J3K) where fisheries for northern shrimp and snow crab spatially overlap to a large degree. Shrimp trawling could damage new-shelled crabs in particular, and it was noted that the shrimp fishery occurs throughout the snow crab moulting and soft-shell seasons (i.e. spring and summer). The 1999 fall survey catch rates of new-shelled crabs were much lower than those of 1998 in Div. 2J3K, but not to the south in Div. 3L where there was no shrimp fishery. However, the decline in survey catch rates occurred only in the most recent year whereas shrimp fishing effort has been high, especially in the most-northern area (Div. 2J), since 1997. Also, the decrease in survey catch rates of small (<75 mm CW) new-shelled males between 1998 and 1999 was more prominent in areas not fished for crab (or, to a large extent, for shrimp) than in areas fished. This suggested that the reduced survey catch rates of small new-shelled crabs in 1999

were not due to shrimp trawling, because small males are distributed mostly in shallow waters on the banks that are not fished for shrimp. Further, the 1999 Div. 3K fall survey catch rate of new-shelled legal-sized crabs in areas that had been fished for shrimp was comparable to that in areas that had been fished for crab but not for shrimp.

Discussion:
Scotian Shelf shrimp fishery observers report that there is very little bycatch of crab in that shrimp fishery. Observer reports in Newfoundland report the same absence of bycatch. Here is still a concern that crab may be damaged by footgear but are never taken by fisheries the fisheries. There is no evidence that this happens but the crab industry argues strongly this is the issue. The possible impacts of bottom trawls are damage to habitat and injury to crab. The Code of Conduct for Responsible Fisheries project is looking at this. There has also been a big increase in fixed gear turbot fishery and bycatch there may be important. The bycatch of crab in the Gulf turbot fishery was quite low overall, but in some local areas it can be very high; up to 50% of the catch of crab. When the possible effects of bycatch due to ghost-net fishing in deep waters are considered as well the total bycatch mortality could be worse.

Studies in Newfoundland show that identification of bitter crab disease is pretty high, and estimated percentages can only be underestimates.

BCD incidence is very low in surveys on the Scotian Shelf and the Gulf. It was noted, though, that those surveys are in the spring and BCD shows up most in Fall. BCD can also expend in frequency very quickly

- **Wade, E. and M. Moriyasu**

Estimating population mortality rates.

Parameters describing the adolescent male population dynamic parameters were derived from histogram distributions established by the annual trawl survey. Skip rates, moulting rates to larger adolescent, moulting rates to maturity and mortality rates were derived.

Mortality rates for adult males were deduced from bias plots of forward and backward calculations. Mortality rates deduced from these bias plots seemed to be higher in the 1994-1999 period than for the 1988-1993 period.

Discussion:
It was agreed that zone 12 is ideal spot for this sort of study, and the research is an excellent approach to infer loss rate.

What were the population trajectories during the study? From 1991 to 1995 it was a growing population, but from 1995 onward there was substantial density dependent mortality.

What is this "loss" – is it temporary (skip moult), permanent (early terminal moult)? Both contribute, and their relative contributions are taken into account

The discard mortality of crab >75 cm could be a source of some of the non-linearity.

When higher skip rates were observed in Newfoundland, the conclusion was that it may be indication that the recruitment pulse is peaking and density dependent processes may be coming into play.

8. PRECAUTIONARY APPROACH

- **Wade, E. and T. Surette**

Precautionary approach to the southwestern Gulf of St. Lawrence snow crab fishery: Theory and applicability.

Discussion:

The first point that was stressed was that this was a complex subject, and the presentation could only give a superficial overview of its many complexity.

There was a long discussion of the Privy Council Office initiative on the Precautionary Approach / Precautionary Principle in government activities. Although the report of that group will not go out for discussion until early in 2001, some argued that DFO should be designing its implementations of the PA around the framework that document is developing. In particular, the PCO framework ties implementation of the PA to risk of serious or irreversible harm to the resource. This has important implications for the biological basis for limit reference points. It may be that limit reference points will have to be somewhat less conservation (lower biomasses, higher exploitation rates) than some fisheries scientists were considering. However, conservation can still be served, because the document encourages very risk averse approaches, so actions can be triggered by even a low risk of exceeding limits. The document also places the PA directly within a risk management context. This also has important implications for the currency of reference points for fisheries; they should be things for which risk analyses can be done.

Some participants felt that it might be necessary to have two sets of reference points for the precautionary fisheries; one set developed along the lines that DFO staff had been pursing, and another set consistent with the PCO framework.

9. SPECIFIC MANAGEMENT ISSUES

a) Appropriate exploitation rates

- **Moriyasu, M. and E. Wade**

Can we estimate reliable exploitation rate for snow crab fishery? Case study in the southwestern Gulf of St. Lawrence and western Cape Breton Island fisheries.

In the past, a target exploitation rate for Atlantic snow crab has been arbitrarily set at the 50-60% level based on the results obtained by catch-effort data analysis (Leslie analysis). In the Southern Gulf of St. Lawrence crab fishery (Area 12), exploitation rates of between 32 and 45% have been applied since 1990 based on the results of bottom trawl survey, which showed a rapid recovery of depressed stock conditions found in 1989. However, in the Western Cape Breton fishery (Area 19), much higher

exploitation (63%) has been applied since 1994 and the stock seems to support the exploitation rate. This high exploitation rate seems to be the consequence of the underestimation of biomass level due to the immigration of commercial-sized crabs between the fall survey and the opening of the following fishing season. This migration seems to occur when the biomass level is higher in the adjacent area (ex. Area 12). Small fisheries with limited surface of prime crab habitat, such as Area 25/26 (amalgamated with Area 12 in 1996), 12E and 18 are also highly dependent on the overflowing biomass from the adjacent main fishery (Area 12), which make the establishment of a sound exploitation rate extremely difficult. It is felt that setting a target exploitation rate to pan-Atlantic snow crab fisheries is premature. The exploitation rate has to be set by taking into account the area specific characteristics of each fishery in question (dynamic phase if the population, migratory characteristics and the possible influence by the adjacent fisheries).

Discussion:
Other discussants agree that some areas can be fished harder than an appropriate average for an entire stock because of productivity differences. Fishers can see the change in productivity associated with increased exploitation, and they often want to get the same increase in their zone. A biologically based strategy can lead to differential exploitation rates at different places and times, but may not sell in the political arena, because it creates a perception of unequal treatment of fishers.

With regard to examples used, areas 18, 19, and 12 are thought to be a common biological productivity unit, so why talk about different exploitation rates in a common unit? The proposal is to set the target exploitation rate for a larger unit than the management boundaries.

The effects of movements are definitely important, but one needs to be very careful comparing among regions. Differences in the survey sampling gears alone may make the exploitation rates not comparable if their catchabilities differ. Were comparisons made between Leslie estimates and survey estimates for Area 12? No, that was not done.

If area 19 and 18 are being supported by immigration from 12, then isn't it the case that Leslie analyses are not appropriate because it is not a closed population? The assumption is that we are working within a single overall closed population.

b) Highgrading

- **Hébert, M. and D. Giard and P. DeGrâce**

Monitoring highgrading activities in the southern Gulf of St. Lawrence.

Active Highgrading:

There are some possible impacts related to active and passive highgrading.

1) Waste of resource, 2) affects reproductive potential of the stock, and 3) affects population size structure. Monitoring is done through observer programs and dockside monitoring by comparing sea average with port average, within an appropriate sector, for three harvest categories (>102mm, mossy, and missing legs).

The results are reported on a daily, weekly, and annual basis to Conservation & Protection, Management and Industry. The results give us a tool for a specific and overall perspective on highgrading behaviour in the fishery. The goal is to reduce this activity by targeting boats and taking administrative measures.

Passive Highgrading: The size of the mesh used on snow crab traps has an impact on the size of captured crab. Presently, the minimum length measures taken inside the knots on one side of the mesh is regulated to 65mm without regulation for the maximum length. To further study the relationship between the mean size of captured crabs and mesh size of traps, we used data collected from the at-sea sampling during the 1999 fishing season. Our results showed that there was no direct effect of soaktime of the trap on the mean size of crabs caught. However, the mesh size had a significant effect on the mean size. Traps with mesh size larger than 80mm caught significantly larger-sized crab that all other mesh sizes. For the 2000 fishing season, the mesh sizes of traps were regulated at 65 to 75mm in order to avoid passive highgrading.

Discussion:
Concern was expressed that increasing mesh size, to reduce retention of small crab might still lead to increases in handling of white crab since more larger, recently moulted crab could accumulate in traps where smaller crab were retained. Others felt this might not be the case.

c) Impact of soft-shelled closures

- **Hébert, M. and M. Godin**

White crab monitoring program in the southern Gulf of St. Lawrence.

Discussion:
With regard to the rules for in-season closures due to levels of soft-shell – what is the source of data on which decisions to close are based? –Are the data only from vessels with observers? Yes

If you had a call from a captain reporting high rates of soft-shell, would the are be closed? No, but an observer would be put on the boat's next trip to that area.

d) Release of adolescent (small clawed) legal sized males

- **Dufour, R.**

Discarding adolescent snow crab during the fishery: Description and trials of a proposed method.

Precautionary discarding of adolescent male snow crab of commercial size during fishing operations increases their chance to moult again, which increases their size and their weight of flesh considerably. Furthermore, it allows them to be able to couple again in the next spring and to contribute to the perpetuity of the population. A crab of bigger size and good appearance generally brings a better price at landing and represents a gain for the fishermen and the industry.

Adolescent males can be identified visually after some adequate training. The male adolescents, so called " crabs with small claws ", are distinguished from male adults, " crabs with bigger claws ", by the size and the shape of their claws which are smaller and longer. To accustom the fishermen to identify these quickly during sorting on the deck of the boat, we suggest the use of a gauge as a learning tool. This gauge allows a fast identification of the adolescent crabs of commercial size between 95 and about 100 mm CW, or the range of sizes where they are present in large numbers during the fishing operations. This new protective measure for adolescent snow crab of commercial size was applied successfully from 1997 to 1999 in the exploratory zones of fishing A and B of the Gulf of Saint Lawrence. This pilot project received a positive answer on behalf of the fishermen of the concerned zones. Fishermen find the current gauge easy to use and very useful for the identification and sorting adolescent males. Results showed that the use of the gauge did not cause significant delays in the sorting operations, or any visible increase of the mortality of crabs during these manipulations. The fishermen generally agreed that discarding of adolescent males should be implemented on a voluntary basis during the fishing operations.

Discussion:

There was a discussion of the relationship between adolescent, white, category I and II, to clarify exactly the criteria for the different classes, and established whether they were distinct or overlapping groups.

If all stage I and II crab were returned to the sea, will all the adolescent crabs be returned? Yes, but for late season fisheries the mix of adolescents and adults presents more of a problem than in other seasons.

It was pointed out that the objective this project was not to prove it was a good idea to return adult small-clawed crab to the water, but to have practical way to do it.

It was also noted that even without gauges fishers can separate large and small claw. However it was contested that not all fishers can, in fact, do this, or at least not do it accurately. Nor are all fishers motivated to do so, even if the ability exists.

Some discussants argued that the issue of the role of the gauge comes back to basically a regulatory consideration. Biologically returning adolescents may be a good idea, but it presents other problems for enforcement when there are other types of high-grading that are serious. Other disagreed, noting that the gauge gives the tool for proving that the crab was not a mossy one and could not be returned.

e) General

- **Vienneau, R. and T. Surette**

Vessel tracking system, Possibility of obtaining an accurate fishery data: case study in offshore snow crab fishery on the Scotian Shelf.

VMS is becoming an acceptable monitoring system for the Conservation and Protection Branch. VMS provides reliable data that can be integrated into the fisheries management process as additional tool from compliance, science, resource management and other aspects of the Departments mandate.

Discussion:
Some felt the VMS system presented great potential both for management on very fine geographic scales, and for demonstrating that fishers are not currently respecting the management lines that are in place.

10. DISCUSSION OF MANAGEMENT STRATEGIES

Before the general discussion began, there was an intervention stressing that the discussions at this meeting were very valuable. However, the communication of the results of this meeting is going to be crucial to the long-term success of any management initiatives that result from these discussions. Fishers have to understand why any changes are being proposed, and have to see why the changes require their support and cooperation.

General Discussions and Conclusions on Links Between Science and Management.

Biological Considerations

The group first itemized the major aspects of crab biology and crab fisheries which could form the basis for sustainable management strategies of crab. In the following discussion the phrase "appropriate" rate will be used, to indicate a management approach which ensures conservation of the resource with high probability, and allows reasonable harvesting opportunities whenever conservation is secure. The group agreed that:

- evidence of diminished reproductive potential was to be considered a threat to conservation, and if observed or projected, would justify management action to reduce or eliminate the threat.
- evidence of only reduced yield or yield-per-recruit from the stock was a concern with regard to optimal harvesting and sustainability of the fishery, but not with regard to conservation of the resource.

Two properties stood out, which, if interpreted broadly, might include the other approaches to management that arose in discussion. These were **exploitation rate** and **mature (spawning or breeding) biomass or abundance**. For both considerations, the questions with regard to appropriate management strategy were:

- Are there any factors which would cause the value of the characteristic that would be optimum for management to vary.
- If so, what are they and why; if not, why not.

The discussion agreed that **the appropriate exploitation rate would likely change over time**, using the following reasoning:

- Optimal exploitation rates commonly are sensitive to natural mortality rate (m) and expected recruitment (R).
- For snow crab populations, both M and R are likely to be variable over time.
- The variability over time in M and/or R is large enough to matter to optimal management, and at least some of the variation may not be completely stochastic.
- The variability is a function of more than spawning biomass (or numbers of spawners)

There was discussion of whether or not the appropriate **exploitation should vary with immigration** into and **emigration** out of a given crab population (where "population" was not defined rigorously). It was proposed that the relationship between appropriate exploitation rate and population exchange (net immigration or emigration) would depend on whether or not the exchange was the consequence of density dependent factors. If the cause were density dependent migrations, heavier harvesting of populations receiving a net gain in immigrants could create a permanent sink for the source population, and result in a higher mortality on the source population than intended. If the migration out of the source population was not sensitive to density of the source population, however, then a higher harvest rate in the sink population would produce improved yield overall, without increasing risk to stock productivity.

Factors Affecting Appropriate Exploitation Rate

There was agreement that the **appropriate exploitation will vary with sex / age / stage ratio**. The rules are important, and developed separately below.
It was also agreed that whatever rules might be developed for relating exploitation rate to other properties of crab populations or fisheries, both target and limit reference points will vary with those properties.

The group reviewed potential considerations with regard to how appropriate management would vary with the production or standing biomass of crab stocks. The primary concern was identified **as foregone yield that would result from harvesting when soft-shell and/or adolescent crabs were common**. This was not a conservation issue but an optimum and sustainable harvest issue. In discussion of potential conservation issues, two were identified:

- Due to lower weight at stage for white or adolescent crab, for a given TAC mortality on the full population would be higher than if catches were all of legal sized, hard-shell crab.
- Due to the periodicity of recruitment, harvesting white or adolescent crabs when they were abundant could result in the loss of a damping effect on variance in breeding population size.

The discussion also noted that similar considerations might apply to harvesting of other life history stages, but the details were not specified. More importantly, it was noted that **losses of yield and possible conservation impacts would depend on the expected survivorship of soft-shell, legal size males returned to the sea**. If mortality was very high, the detrimental impacts would be expected to occur whether the crabs were landed or not after being retained in the gear.

In the consideration of the topics which follow, it was also noted that there needed to be discussion at some point on the best measure for **reproductive potential**. The conventional notion of "spawning stock biomass" used in marine fishes was not appropriate, both because of the male-only harvest and because note all "mature" males and "mature" females have equal reproductive value. It was thought unlikely to be able to resolve this issue during this meeting, but the use of sperm biomass as a currency was proposed. It was also agreed that with present knowledge **Reproductive Potential is best protected by ensuring that stage 2-4 post-terminal-moult males are adequately represented in the populations.**

It was also highlighted that in evaluating consequences of management options, the discussions should specify, to the extent possible both long-term and short term considerations.

In reviewing the considerations of harvesting rate with regard to **change in natural mortality** it was noted that there are several **causes of change in M**, including:

- M may be a function of recruitment pulses, with M relatively high when recruitment is increasing, so a relatively large fraction of the population was undergoing moults. Because of existing sampling regimes, M might be estimated to be particularly high as males approached their terminal moults.
- M might be increased when the adult population contains a large portion of mossy crab.
- There is some evidence suggesting that the contribution of disease to M may be a function of density.

The proper management response to increasing M will be developed below.

In reviewing the considerations of harvesting rate with regard to **changes in sex/stage ratio** it was noted that the concern was the change in abundance of effective breeders, and these needed to be specified clearly. It was agreed that the most important considerations on effective breeders are that:

- The **most valuable males** with regard to reproductive potential are **males of stages 2 to 4 post terminal moult**. Often **a close surrogate for this measure is the percent of males in shell conditions III and IV**
  The **most valuable females** with regard to reproductive potential are **pubescent and primiparous females**. (Note: pubescent females become primiparous after molting and laying their first egg clutch, thus they are in a sense the same type of females. Pubescent-primiparous females are to be contrasted with multiparous females. It is premature to say if pubescent-primiparous females are more valuable than multiparous females with regard to reproductive potential. However, the pubescent-primiparous stage is clearly a critical step in the female's reproductive life; mating success at this stage will condition female life expectancy, depending on level of injury sustained, and autonomy from further re-mating, depending on the size of accumulated sperm stores.)

The advised management strategy is that when the ratio of stage 2-4 post-terminal-moult males / pubescent and primiparous females is low, the exploitation rate should be reduced. This is to ensure that the pubescent primiparous females, who have high reproductive value (See Bernard's comment above), are inseminated by males who transfer large amounts of quality sperm. The reduction normally would last for only a couple of years. The reason for the short duration is that males from the same recruitment pulse which produced the relatively large number of primiparous females would on average have their terminal moult only slightly later than the earlier maturing females. (Note: females and males grow at the same rate, they differ however in the mean post-settlement time for the terminal molt to maturity). As they matured, the ratio of stage 2-4 post-terminal-moult males to pubescent and primiparous females (whose numbers would be declining somewhat as the recruitment pulse passed through the population) would be restored.

The justification for this management strategy is avoidance of several risks:

- Risk of **loss of future reproductive potential** if pubescent primiparous females are inseminated by males who are ineffective, or who transfer small amounts of sperm.

- Risk of **loss of genetic diversity** if relatively small numbers of males inseminated many females
- Risk of **directional selection towards smaller males**, and males which have terminal moults at smaller sizes.

It was noted that there are important spatial aspects to appropriate management of snow crab. Important considerations were identified, including:

- **Production of new snow crab is not completely dependent on local breeding populations**, although the degree of population fragmentation is variable around Atlantic Canada.
- Well before crabs have recruited to legal size or breeding condition they have become part of **a standing stock that is largely resident**
- **There is a risk of local depletion of through local overharvesting**.
- **Local depletion** of important reproductive stages **could result in loss of future reproductive potential.**

It was agreed **that there are important benefits to matching management to appropriate spatial scales**. The possible strategy is that harvesting can be used to improve sex and stage ratios relative to optional ratios, working at meaningful biological scales. **The result would be to increase yield and reproductive potential locally and overall.** It was also noted that adjustments of harvesting rate at local scales would require a great deal of science support, and often might not be operationally feasible. The tool to achieve this would be adjustments to the seasonality of harvest.

The group agreed that harvesting rules above would not necessarily work in reverse. If the ratio of stage 2 to 4 post-terminal moult males to pubescent primiparous females is **high** the best management approach would depend on the numbers of females and males which are following in the population. The ratio should be viewed in the context of husbanding the reproductive potential of the stock. The optimal usage of the temporary possible surplus of stage 2 to 4 post-terminal moult males would depend on whether the incoming cohort was likely to include more maturing males (in which case harvesting more of the standing stock would result in maintaining adequate numbers of males for mating) or maturing females (in which case more older males might be required for optimal insemination of females).

Discussion considered explicitly the optimal harvesting strategy relative to the **percent of adult males of legal size**. The impacts of a disproportionate proportion of just-matured males on stock reproductive potential are uncertain. There is a possibility of competition for food and females, but no strong evidence that they are effective competitors versus the "optimal" males of ages 2-4 post-terminal moult. Exploitation patterns which increase the proportion of just-matured males in the population also presents the possibility of medium-to-long-term risks of change in population genetics towards earlier or smaller maturation because post moult males are poor mates. Because of these considerations the management response would not be based on short-term conservation considerations: the short term impacts are highly situation-dependent with regard to operational sex ratios, whereas the long-term risks are highly uncertain. Nonetheless, increasing harvest of newly-maturing males will generally led to substantial loss of yield, and for that reason alone it would sub-optimal to increase harvest of newly-matured males just because of a temporary abundance of them.

The group also discussed harvesting strategies from the context of whether **strategies** should try **to preserve specific ratios and numbers of females with different reproductive histories** (primiparous, multiparous, etc). It was agreed that females reproductive potential is already addressed as the denominator of the ratio discussed in the preceeding paragraph. Hence it is already considered under harvesting strategies relative to ratios of males to females. Therefore any conclusions from ratios of females from different stages should be the same as already produced by the male to female ratio. It was noted, that the value of the true functional ratio of reproductively valuable males to reproductively valuable females is a source of uncertainty because multiparous females may be more fecund than primiparous females and their progeny may differ in quality (growth and survival potential). However, this source of uncertainty applies equally in all contexts

The final harvest rate consideration dealt with **harvesting of adolescent males**. It was agreed that the major issue was not conservation of reproductive potential, as long as the factors discussed immediately above are addressed. Nonetheless, there were several potential negative consequences of harvesting adolescent males.

- The major undesired consequence was substantial loss of yield per recruit.
- Harvesting adolescent males would also result in greater mortality rate for given TAC, if the TAC was set assuming a weight at length of a fully hard-shell crab, yet much of the TAC was taken as adolescent or white-shell males.
- It was further noted that there was a possibility of detrimental effects on reproductive potential in the medium to long term, due to possible selection for early maturation
- Another impact of harvesting of stage 2 males is that in subsequent years it the reduces dampening effects on population fluctuations, making the population more unstable.

Precautionary Approach Framework

After discussion the group agreed that in the context of snow crab assessment and management, implementation of a Precautionary Approach would focus on three factors:

- Maintaining desired ratios of types of males and females
- Protecting a proper size composition, particularly of males
- Protection of juvenile nursery grounds from damage or mortality to young crabs.

Use of a Precautionary framework also requires that uncertainties must be estimated. Among the most important uncertainties the group specified spatial aspects of the population and its component sex and maturity stage groups, and identification of nursery grounds. The group agreed that early benthic settlement was a poorly known but important part of crab population dynamics. It was also agreed that uncertainty about the role of benthic settlement as a possible bottleneck in stock production does not negate the desirability of maintaining high egg production. In fact, a precautionary approach would support giving high priority to maintaining optimal egg production until the limiting factors on settlers (or, early juveniles), and its role in overall snow crab population dynamics, were well understood. At the same time, the PA justifies strong measures to ensure protection of crab nursery areas, to avoid incremental mortality on small crabs.

The spatial uncertainties are associated with the question of whether there are source and sink meta-populations of snow crab, what is their biological basis, where source and sink populations might be, and how to identify each type of population. It was agreed that source areas, if identified, need particularly risk averse management. However there was no certainty that sink populations could have higher exploitation rate. There was concern that if

part of the movement into "sink populations" (if they exist) was due to density dependent factors, increased exploitation of sink populations would exaggerate the difference in density, prompt greater migration from source to sink populations, and result in greater loss to the source population as well.

Stock Definition

Based on the presentations and discussion, the group agreed that **the concepts of clines and /or metapopulations apply to snow crab.** That is, the populations cannot be considered panmictic in areas as large as the Newfoundland Shelf or northern or southern Gulf. Nor, however, do they comprise many discrete and largely isolated meta-population units that re-colonize, persist for a period, and then go locally extinct. Rather, mating is likely to occur at fairly local scales (perhaps 10s of kilometers at most) but there is likely to be some exchange along continuous gradients of occurrence. Moreover, the degree to which local recruitment is dependent on local spawning is unknown, as larvae may be transported substantial distances.

The group also agreed that for essentially every part of the Atlantic **information is insufficient to delineate functioning stock units at the clinal or meta-population scale**. There was agreement that major physical barriers do matter to population structure, but the only ones we see are very large scale properties, such as the Laurentian Channel. Physical barriers at other scales may also be important to snow crab meta-population structure, but are not yet well enough studied. Notwithstanding the lack of information, there was agreement on the relevant criteria for judging population structure, were information to become available, and for management decisions with current information. The key considerations would be:

- Common production dynamics
- Continuity of distribution

Recruitment Mechanisms

Although the factors which control year-class strength are not known, a number of factors have been shown to influence reproduction on at least local, and sometimes population scales. These include both density dependent and density independent factors. With present knowledge the factors can be listed, but not even rank ordered by importance. In fact, it is likely that the relative importance of the factors will vary across the Atlantic zone, and for individual areas may differ among years. The **Density Dependent Factors include:**

- Cannibalism,
- Nursery Competition
- Disease
- Larval Supply; whereas the major Density Independent factor is thought to be the amount of area of favourable temperature for larval and benthic settlement

There was concern that there could be additional sources of natural mortality of young crab, as well. Data are lacking to demonstrate predation by any specific species of fish or marine mammal is sufficient to regulate snow crab recruitment. Nonetheless, it is possible that if groundfish rebuilt to historic abundances the predation mortality they would inflict would be additive to current sources of mortality, depressing recruitment overall. Although this possibility needs to be considered seriously, it was also agreed that potential predation mortality cannot be scaled analytically to relative indices of current abundance and

exploitation. Too many things have changed about the Atlantic marine ecosystems to allow recent data to be extrapolated to very different conditions of the ocean environment and predator community. With present knowledge these considerations should be addressed in the section on Source of Uncertainty in assessments and SSR. However, consequences of various possible scenarios of rebuilt groundfish stocks should not be forecast analytically with present knowledge.

Comparison Of Assessment Methods

Data Sources:

LOGBOOKS:

Newfoundland

- Format – General fishery logbook
- Reliability – Differing views were expressed. All agreed that they were OK for trends, but reporting was not standardized so little precise information could be extracted.
- Coverage – all fisheries and fleets of which between 55-85% are temporary license holders.
- Data – effort [type and # traps, soak time], catch [verified] (CPUE), location [lat - long],
- Discards - self-reported as narrative or estimates of amounts

Southern Gulf and eastern Nova Scotia

- Format – Special Crab Logbooks
- Reliability – High
- Coverage – All fisheries (95% of data are usable)
- Data –Effort [type & # of trap hauls, soak times] catch [verified](CPUE)
- Location – lat-long , depth
- Discards - self-reported narrative information

Northern Gulf

- Format – Special crab logbook
- Reliability - high
- Coverage – All fishers
- Data – Effort [type& # traps hauls. Soak times], catch [verified] (CPUE)
- Location – grid (until 99) now lat-long
- Discards , self- reported narrative

OBSERVERS:

Newfoundland:

- At sea
- Coverage - ~ 10% regular, 100% exploratory
- Science input to allocation of coverage – none
- Data – Catch, Effort. (CPUE), Location (accurate), Discarding, % white crab; biological measurements, mesh size, bait covers, damage; disease
- Dockside

- Coverage – 100%
- Data - Catch, effort, some biological sampling

Southern Gulf and eastern Nova Scotia
- At sea
- Coverage 5-15% in Southern Gulf and 5-20% in eastern Nova Scotia
- Science input to allocation of coverage - some
- Data – Discarding & High-grading practices from size distributions, % white crab; biological characteristics, mesh size, depth, catch and effort
- Dockside
- Coverage – 100%
- Catch, (see port sampling for other information)

Northern Gulf
- At sea
  Coverage - 15%
  Science input to allocation of coverage - informal
  Data –Size distributions, % legal, Biological traits. Catch & effort, white crab
- Dockside
  Coverage – 100%
  Catch, sampling for size composition

PORT SAMPLING

Newfoundland – None

Southern Gulf –
- Coverage – 30%
- Data - all biological measures of at-sea sampling.

Eastern Nova Scotia
- Coverage <10%
- Data - all biological measures of at-sea sampling

NG
- Coverage – 5-10%
- Data - Some biological measurements

TRAWL SURVEY

Newfoundland
- Design - Multispecies survey using stratified random design and at least 2 sets per stratum. Stratification based on depth and latitude.
- Coverage – All of 2J3KLNO. Survey area includes some "noncrab" areas in 3NO. Inshore areas only surveyed since 1996,
- Gear - Campelan shrimp gear; rockhopper
- Basic data and derived measures- Catch per tow; Minimum trawlable biomass from STRAP (used as an index). Size distributions overall and by area
- Timing - Near end of fishery.

Southern Gulf

- Design - Dedicated snow crab (industry funded) using fixed stations. One set per grid square
- Coverage – only recognized crab areas (deeper than 20 m)
- Gear - Nephrops gear with tickler chains and SCANMAR
- Basic Data and derived measures - Catch per tow and size composition per tow. Produce integrated biomass estimates from kriging that are used as absolute biomass
- Timing - After fishery is finished

Northern Gulf

- Design - Dedicated snow crab survey. Random allocation until 1997 and fixed grid stations thereafter.
- Coverage – variable across different areas
- Gear - Beam trawl with tickler chain
- Basic Data and derived measures - Catch per tow and size composition per tow. Produce integrated biomass estimates from kriging, and are used as relative indices of abundance for each class of crab
- Timing - Near end of the fishery

TRAP SURVEY

Newfoundland –

- Design - Paired sampling with a trawl sample at each site
- Coverage - Limited spatial coverage
- Data and derived measures - Composition of population by type of crab. Abundance index for trends from CPUE, for area covered. Monitor females for fertilization condition
- Timing - During the fishery, and different seasons at different places.

Southern Gulf

- Design - Focused on specific questions
- Coverage - Limited spatial and temporal coverage,
- Data and derived measures - For information on local conditions and events

Northern Gulf

- Design - Systematic line survey. Industry fishes and partial finances
- Coverage – Started with limited coverage in 94 Full coverage since 1999
- Data and derived measures - Abundance index of trends in area samples. Short term status indicators of crab stages and conditions.
- Timing - During and after fishery

ADDITIONAL TRAWL SURVEYS
Newfoundland only

Population Analyses

Newfoundland

- Examine trends in CPUE from surveys, logbooks, observers
- Conduct exploitable biomass projections from survey numbers at length using STRAP analysis including all strata between 50-1500 m
- Estimate relative exploitation rate and multiply by estimated exploitable biomass, including all shell categories of legal sized males
- Apportioning of estimated sustainable catch across areas, is "soft"; guided by regional patterns in CPUE and survey catches, and considering biological narrative information.

Southern Gulf

- Examine trend in "absolute" biomass from kriging.
- Conduct exploitable biomass projection from kriged density at length x wt at length x area kriged, for legal portion of population.
- Repeat projections for abundance (no weight vector) for other categories of population
- Apply ~32% exploitation rate x projected biomass of adult males (excluding old, mossy males – "graveyards" – not expected to contribute to catches) >95 mm
- Percentage exploitation rate can vary from year to year for biological reasons.
- A lower exploitation rate is used in eastern Nova Scotia

Northern Gulf

- Examine trends in both surveys and commercial CPUE to evaluate impact of recent exploitation relative to incoming recruitment.
- Apply current index values from kriging using density, not biomass
- Consider trends in biological traits (sex ratio, presence and condition of spermatheacae, etc.)
- React to three year trend in recent index to adjust harvest relative to relative density indices
- Conduct one season forecast in size composition using relative density estimates of "all" type of crab
- No estimation of exploitation rates

Major Differences among Regions

1) Survey type and coverage –
Reason - Money available for vessel time. Secondary effect of differences in amount of crab habitat that can be trawled.
Consequences –
Cannot use survey values as even approximation to absolute biomass where coverage is markedly incomplete, and therefore also can't estimate exploitation rate directly from the survey results.

Makes risk quantification more difficult, and it is only possible to estimate how risk varies with catch and other factors – not how large the risk actually is.

2) Soft-shell closure protocols
Reasons - Different priority to management in different Regions
Consequences -
Different losses in yield due to different exposure to harvesting in areas with mortality due to handling soft-shell crab.
Increased mortality due to discarding in areas open longer.
Possibility of long-term population effects of harvesting pre-breeding males

3) Presence of both Port Samplers and DMP –
Reason – money available for observing catch
Consequences –
Without both there is no ability to compare size composition and shell condition of at sea catches to landings
Hence there is poorer ability to quantify high-grading

4) Length and timing of fishing season
Reasons –
Oceanographic and weather conditions mean safe and efficient harvesting times differ.
Need for accommodation of other fishing seasons;
History & inertia in individual regions
Processor and market differences among Regions
Consequences –
More white crab are taken in fall fisheries, producing greater impacts on next year's recruitment.
Recruitment has to be calculated differently in assessments to acknowledge contribution of white crab to catches in regions with Fall fisheries.
This produces a reduction in yield-per-recruit.

5) Exploitation of new-shell crab
Reason – same as for 4).
Consequences – same as for 4)

6) CPUE adjusted for soak time
Reason – Some Regions are getting the necessary information from logbooks, but others are not. Where it is done there is some concern that meaningful adjustments are not possible due to questionable quality of the information on soak times.
Consequences – Lower precision and possible biases in CPUE

7) Timing of Reseach vessel and industry surveys
Reasons –
Suitable weather windows are not identical.
Surveys are multipurpose and timing was set when crab were not a target of the survey.
Timing of the fisheries are different.
Consequences
Can't compare ratios of various types of crabs across surveys, due to likelihood that catchabilities may differ, and that shell types available at different rates in different seasons.

Can't compare absolute harvesting strategies across regions, because populations being exploited are in different condition.
Different information provided about status of stock, including female fecundity rates, moulting frequencies, and disease levels.
Terminology for discussion fishery events becomes confusing outside local user community.

8) High-grading – rates and measures
Reasons –
Different market requirements affect true rates of high-grading.
Effect of differences in port sampling and observer coverage affect costs of high-grading to industry.
Consequences -
Potential for large effects on reproductive potential (Discussed in section 8). Differential ability to enforce compliance with regulations.
Biases in estimation of harvest rates, such that effects of fishery on stock may be underestimated.
Increased high-grading increases effective fishing effort experienced by stock.
Increased discard mortality caused by fishery where high-grading is higher.

APPENDIX I: Agenda

ZONAL WORKSHOP

SNOW CRAB MANAGEMENT STRATEGIES

MONTREAL, QUEBEC

NOVEMBER 21-23, 2000

AGENDA

1. **Opening remarks *(J. Rice)***

2. **Adoption of the Agenda *(J. Rice)***

3. **Review of the Terms of Reference *(J. Moores)***

4. **Science Workshop Report *(E. Dawe/B. Sainte-Marie)***

5. **Regional Assessment Methodologies**
   - Dawe, E and D. Taylor

   Methodology for estimation of Newfoundland and Labrador snow crab biomass indices and resource status from multispecies surveys and the analysis of commercial fishery data.

   - Moriyasu, M. and M. Hébert

   Methodology of data analysis used for the stock assessment for the southern Gulf of St. Lawrence and Eastern Nova Scotia.

   - Dufour, R. and B. Sainte-Marie

   Stock assessment methodology in the northern Gulf and Estuary of the St. Lawrence

6. **Regional Management Approaches *(Regional Fisheries Managers)***

7. **Specific Science Issues**
   a) **Stock definition: Biological and management definitions**
      - Sévigny, J.-M.

      Snow crab population genetic structure in the Northwest Atlantic: discrete stocks or metapopulation.

   b) **Distribution and movement of snow crab**
      - E. Colburne, D. Orr and E. Dawe

      Distribution of Newfoundland and Labrador snow crab in relation to bottom temperature from fall 1995-99 multispecies surveys.

      - Surette, T. and M. Moriyasu,

Distribution of modeled moult and maturity groups of snow crab (*Chionoecetes opilio*) in the southern Gulf of St. Lawrence.

- Savoie, L. and M. Biron,

Movement of snow crab in the Gulf of St. Lawrence and on the Scotian shelf by means of tag/recapture study.

c) Crab recruitment mechanisms

- Sainte-Marie, B. and R. Dufour

Periodic recruitment patterns in snow crab and the potential underlying mechanisms.

- Taylor, D.

Inshore trapping/trawling surveys as indicators of recruitment trends, BCD prevalence and commercial abundance in Newfoundland.

d) Conservation of reproductive potential

- Sainte-Marie, B.,

Sexual competition, male allocation strategies, and reproductive success of female snow crab.

- Sainte-Marie, B.

Ageing and changes in condition of male snow crab after the terminal moult.

e) Sources of mortality other than the crab fishery.

- Dawe, E.

A consideration of potential effects of bitter crab disease (BCD), discarding and shrimp trawling on Div. 2J3KLNO snow crab mortality.

- Wade, E. and M. Moriyasu,

Estimating population mortality rates.

8. Precautionary Approach

- Wade, E. and T. Surette,

Precautionary approach to the southwestern Gulf of St. Lawrence snow crab fishery: Theory and applicability.

9. Specific Management Issues

a) Appropriate exploitation rates

- Moriyasu, M. and E. Wade

Can we estimate reliable exploitation rate for snow crab fishery? Case study in the southwestern Gulf of St. Lawrence and western Cape Breton Island fisheries.

b) Highgrading

- Hébert, M. and D. Giard and P. DeGrâce

Monitoring highgrading activities in the southern Gulf of St. Lawrence.

c) Impact of soft-shelled closures

- Hébert, M. and M. Godin

White crab monitoring program in the southern Gulf of St. Lawrence.

d) Release of adolescent (small clawed) legal sized males

- Dufour, R.

Discarding adolescent snow crab during the fishery: Description and trials of a proposed method.

e) General

- Vienneau, R. and T. Surette

Vessel tracking system, Possibility of obtaining an accurate fishery data: case study in offshore snow crab fishery on the Scotian Shelf.

10. Discussion of Management Strategies

11. Workshop Report

SNOW CRAB WORKSHOP

TERMS OF REFERENCE

PURPOSE:

Snow crab (Chionoecetes opilio) is fished commercially in all four Atlantic Regions. However, there is great variation in the methodology used to evaluate the status of the stocks and in the type of advice provided to managers. As well, there are a number of significant biological issues that need to be considered in providing a sound basis for scientific advice, and these require review at the zonal level.

In order to address these issues, the workshop shall:

1. Document the methodologies used by each Region to assess the status of snow crab stocks.

2. Propose comparable approaches, where appropriate, for collecting of biological data and for conducting and analysing survey data.

3. Detail the current scientific view on the following issues:
   - How should a crab stock be defined and are current stock definitions appropriate?
   - What are the recruitment mechanisms for crab and the density dependent and independent factors that influence recruitment?
   - How can the spawning potential be conserved, particularly in relation to the exploitation of large, old males?
   - How can additional sources of mortality, such as disease, discarding and the impact of fisheries for other species be considered in assessing crab stocks.

4. Identify the most appropriate harvesting strategies for snow crab, in light of current biological knowledge, and document these in such a way that they can be applied in regional snow crab management plans in future. Issues which should be considered include:
   - Appropriate exploitation rates.
   - Release of adolescent (small clawed) legal sized males.
   - Impact of closures for soft shelled crab.

5. Specify how the Precautionary Approach should be applied to crab stocks. If possible, appropriate target levels and limits should be stated.

ATELIER SUR LE CRABE DES NEIGES

PROGRAMME

OBJET :

Le crabe des neiges (*Chionoecetes opilio*) fait l'objet d'une pêche commerciale dans les quatre Régions de l'Atlantique. Cependant, il existe une grande variation dans la méthodologie employée pour évaluer l'état des stocks et dans les types d'avis fournis aux gestionnaires. En outre, plusieurs paramètres biologiques importants doivent être considérés pour bien fonder les avis scientifiques, et ces paramètres doivent être examinés à l'échelle zonale.

Dans l'examen de ces questions au cours de l'atelier, on invitera les participants à :

1. Documenter les méthodes utilisées par chaque Région pour évaluer l'état des stocks de crabe des neiges.

2. Proposer, au besoin, des approches comparables pour la collecte des données biologiques et pour la collecte et l'analyse des données de recensement.

3. Préciser quelles réponses la science actuelle peut apporter aux questions suivantes :
- Comment devrait-on définir ce qu'est un stock de crabe, et est-ce que les définitions actuelles sont adéquates?
- Quels sont les mécanismes de recrutement chez le crabe et les facteurs dépendants et indépendants de la densité qui influent sur le recrutement?
- Comment peut-on conserver le potentiel de reproduction, particulièrement en rapport avec l'exploitation des gros mâles âgés?
- Dans l'évaluation des stocks de crabe, comment doit-on prendre en considération les sources additionnelles de mortalité, comme la maladie, les rejets et l'impact des pêches d'autres espèces?

4. Établir les stratégies de récolte du crabe des neiges les plus appropriées à la lumière des connaissances biologiques actuelles, et les documenter de telle sorte qu'elles puissent être appliquées dans les plans régionaux de gestion du crabe des neiges dans le futur. Diverses questions devraient être considérées ici, dont
- Les taux d'exploitation appropriés.
- Le rejet des mâles adolescents (à petites pinces) de taille légale.
- L'impact des fermetures imposées en raison d'un pourcentage trop élevé de crabes à carapace molle.

5. Préciser comment le principe de précaution devrait être appliqué aux stocks de crabe. Si possible, des niveaux cibles et des limites de capture appropriés devraient être établis.

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